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EFFECTS OF FUMIGATION FOR INSECT CONTROL

on seed germination

TEXAS AGRICULTURAL EXPERIMENT STATION

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SUMMARY

Seven fumigants were used to treat seed of barley, oats, wheat, rice, cotton and two varieties of corn and sorghum to determine the effect of fumigation on germination. Seed were fumigated once at three moisture levels and at three temperatures. Selected seed lots were fumigated twice. Germination analyses were made immediately after fumigation and again after 12 months' storage.

Generally, high moisture content of the seed and high temperature during fumigation reduced viability. High moisture content and high temperature usually interacted to produce extensive injury. Fumigated seed of all crops produced seedlings that were less vigorous than nonfumigated seed even when germination percentages revealed little or no differences.

There were no differences between varieties of corn or sorghum in their response to fumigation. Fumigation decreased the rate of germination in stored seed. Germination tests should be performed immediately before sale if fumigated seed have been in storage for a prolonged period.

The fumigants included in these tests were classified in three groups on the basis of their effects on seed germination. Generalizations do not apply in every case to all types of seed since there is considerable variability in susceptibility of different species.

Hydrogen cyanide and carbon tetrachloride in the first group had relatively little harmful effect on germination of seed. Germination was not affected immediately after fumigation with these materials. After 12 months' storage of fumigated seed, reductions occurred in some crops without regard to temperature or seed moisture during fumigation. The germination of seed subjected to two fumigations with cyanide was not adversely affected. No seed were fumigated twice with carbon tetrachloride alone.

The second group of fumigants consisted of mixtures of: (1) ethylene dibromide + carbon tetrachloride; (2) ethylene dibromide + ethylene dichloride + carbon tetrachloride; and (3) carbon disulfide + carbon tetrachloride + inert ingredients. These mixtures at 60° F. and 80° F. had little immediate harmful effect on germination. Fumigation at 95° F. caused no harmful effects when seed moisture was below 15 percent. Two fumigations with the ethylene dibromide + carbon tetrachloride combination caused little damage, but extensive injury followed the use of the other two compounds. When seed were stored for 12 months after fumigations at 60° F. and 80° F., germination declines usually occurred regardless of moisture content.

The third group contained methyl bromide and a mixture of carbon disulfide + sulfur dioxide + carbon tetrachloride + inert ingredients. The latter mixture suppressed seed germination of most species under every fumigation condition. Least injury was caused in the treatment that combined the lowest seed moisture content and the lowest temperature during fumigation. Methyl bromide caused little immediate harmful effect on seed fumigated at low temperature (60° F.). Germination was immediately affected after seed fumigation at 80° F. at higher moisture content levels. Two fumigations always caused severe injury. Drastic reductions in germinations appeared after 12 months' storage for several kinds of seed fumigated with these materials.

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Effect of Fumigation for Insect Control on Seed Germination

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THE DESTRUCTION OF INSECT PESTS ON SEED in storage is one of the most perplexing problems facing seed producers. Present methods of control are confined largely to the use of insecticides which kill either by contact with an insecticide sprayed or dusted on the seed, or by the fumigant action of a vaporized chemical.

The latter compounds are widely used and have certain advantages. Insect pests may be eliminated by fumigation immediately after the infested seed are harvested, preventing additional injury after storage. Within the storage facility, fumigants penetrate readily and kill insects, which may be located in cracks and crevices, thus preventing immediate reinfestation. Also, fumigated seed do not contain concentrations of insecticide residues which may be harmful to individuals who handle the seed or to livestock if the seed are diverted into feed channels. However, repeated fumigations of seed with compounds containing bromine may increase the concentration of this element in the seed to proportions which exceed the tolerance approved by the Pure Food and Drug Administration.

The use of fumigants also has serious disadvantages. Because toxic residues do not persist on fumigated seed, reinfestation by insect pests from untreated areas may occur shortly after treatment. Only those insects are killed which are present when the fumigant is applied. Tight enclosures are necessary for fumigation not only to prevent the fumigant from escaping but to reduce the possibility of immediate insect reinfestation.

Probably the most significant problem associated with fumigation of seed is the tendency of certain fumigants to reduce germination under adverse conditions of application. Many seedsmen have had serious damage claims filed against them because of the failure of fumigated seed to germinate when planted in the field. Official germination tests may have been performed on the fumigated seed several months before sale and the seedsman may have no idea that his seed were low in quality.

A poor stand frequently results when the seed are planted in the field under soil temperature and moisture conditions which are not optimum for germination and plant development. The effect that specific fumigants have on germination and vigor of seed and the conditions under which they may be most injurious are not known. This study was initiated to determine these factors so that seedsmen can store and sell fumigated seed more successfully without suffering financial loss.

PROCEDURES

Selection of Fumigants

Previous studies on the effect of fumigants on germination have been limited largely to the use of methyl bromide and hydrogen cyanide (1, 3, 5, 6, 7, 8).

Hydrogen cyanide and methyl bromide were the first two materials included in the studies reported here. In addition, five liquid fumigants were included in the tests. These seven fumigants and the dosages at which they were used are presented in Table 1. These materials were selected to evaluate the effect on germination of individual components of commercial grain fumigants.

Since carbon tetrachloride is present in most liquid fumigants, it was included as the third material. Ethylene dibromide is also included in a number of commercial grain fumigants. A

TABLE 1. THE CONSTITUENTS AND DOSAGES OF FUMIGANTS USED IN GERMINATION STUDIES

Fumigant	Dosage per 1000 cubic feet
1. Hydrogen cyanide	3 pounds
2. Methyl bromide	1.3 pounds
3. Carbon tetrachloride	3 gallons
4. Carbon tetrachloride — 95 percent + ethylene dibromide — 5 percent	3 gallons
5. Carbon tetrachloride — 63.6 percent + ethylene dibromide — 7.2 percent + ethylene dichloride — 29.2 percent (Dowfume EB-5)	3 gallons
6. Carbon tetrachloride[1] + carbon disulfide + sulfur dioxide + inert ingredients (Stauffer 80-20)	3 gallons
7. Carbon tetrachloride — 82.5 percent + carbon disulfide — 16.5 percent + inert ingredients — 1 percent (Dow Vertifume)	3 gallons

[1]Percentage of each ingredient withheld by manufacturer.

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special mixture of 95 percent carbon tetrachloride and 5 percent ethylene dibromide was prepared and utilized as the fourth fumigant in the test. By comparison of seed germination in the carbon tetrachloride treatment with that in the treatment using this mixture, it was possible to determine whether seed viability declined as a result of the inclusion of ethylene dibromide.

The fifth fumigant was a commercial compound selected to evaluate the effect of ethylene dichloride. Reduction in germination beyond that caused by the fumigant discussed above could be attributed principally to the addition of ethylene dichloride.

The sixth mixture consisted of carbon tetrachloride, carbon disulfide and sulfur dioxide plus inert ingredients. The effect of sulfur dioxide on germination could be evaluated by comparison with the fumigant immediately following.

The seventh fumigant was a commercial mixture of carbon tetrachloride, carbon disulfide and inert ingredients. Reduction in germination caused by this material beyond that caused by carbon tetrachloride alone could be attributed to the addition of carbon disulfide and inert ingredients. No attempt was made to separate the effects of carbon disulfide from those of the inert ingredients.

All of the seven fumigants included were applied at the dosages suggested by the manufacturers for effective insect control (Table 1).

Selection of Kinds of Seed

Previous studies show that the seed of different crops vary in susceptibility to injury caused by fumigation (9).

However, no differences in susceptibility of varieties of the same grain have been illustrated (4, 5, 6, 7, 8).

Seed of seven of the most economically important crops were selected for inclusion in these tests to determine their susceptibility to injury by fumigants. They were corn, sorghum, oats, wheat, barley, rice and cotton. Corn and sorghum were represented by two varieties. The duplication was considered necessary because hybrid seed of these crops is expensive to produce and seedsmen suffer serious financial losses if the seed are sold for grain. Consequently, seed are frequently carried over from one year to the next, increasing the necessity for insect control. A list identifying the varieties of seed used is presented in Table 2.

TABLE 2. VARIETIES AND MOISTURE CONTENT OF FUMIGATED SEED

Varieties	Moisture percentages
1. Yellow corn (Tx 303 x Tx 203)	11-13-15
2. White corn (MO 22 x Tx 61 m)	11-13-15
3. Grain sorghum (7078)	11-13-15
4. Grain sorghum (Plainsman)	11-13-15
5. Barley (Cordova)	11-13-15
6. Oats (New Nortex)	11-13-15
7. Wheat (Westar)	11-13-15
8. Rice (Century Patna)	11-13-15
9. Cotton (Austin)	6- 8-11

Moisture Content of Seed during Fumigation

Previous research has demonstrated that a high seed moisture content increases the possibility of fumigant injury to germination of certain grains.

In this study each type of seed was fumigated at three moisture levels (Table 2). These levels were established by estimating a high, medium and low moisture content for storage of each type.

Seed moisture adjustments were made prior to fumigation. To insure that the seed of each crop were of comparable quality, all samples were taken from a single large batch. Several representative checks were made with a Steinlite Moisture Tester to determine the average seed moisture content. The seed were divided into three lots and all moisture adjustments were made simultaneously.

Seed with too high a moisture content were dried in a forced air circulation system. Moisture checks were made periodically throughout the drying operation to determine when the desired moisture levels were obtained. After drying, the lots were divided into 1,000 gram samples, placed in polyethylene bags and sealed.

In those samples in which it was necessary to increase the moisture content, a calculated amount of tap water was added to each polyethylene bag containing 1,000 grams of seed. To determine the grams of water to add to each 1,000 gram bag, the actual moisture percentage was subtracted from the desired percentage and multiplied by 10.

After the water was added, the bags were sealed and the grain thoroughly agitated.

After the samples were packaged and sealed, they were placed in a room maintained at a temperature of 60° F. At the end of the second and fourth day of storage, the seeds were agitated in the bags. The samples remained in the room for a period of at least 2 weeks before another moisture content determination was made. This period allowed time for the moisture to reach equilibrium throughout the seed mass.

In many instances, more water was added to increase the moisture content, particularly in samples adjusted to the high moisture level. After the second addition of water, the seeds were treated in the manner discussed previously and placed in the storage room for another 2 weeks.

Immediately before fumigation, checks were made to determine whether the desired moisture level had been maintained. The variation allowed was ± 0.5 percent from the desired level.

Temperature during Fumigation

Another factor which influences fumigant injury to germination is the temperature of the seed during fumigation. Several researchers have reported that fumigation with methyl bromide at high temperatures may reduce germination while treatment at lower temperatures has little adverse effect.

It is often necessary to fumigate immediately after harvest under high temperature conditions. This necessitates an understanding of the effect of fumigants on seed treated at both high and low temperatures. Fumigation temperatures of 60° F., 80° F. and 95° F. were selected to provide a satisfactory range. Two replications of each fumigant at each moisture level were used at every temperature on all varieties. Desired temperatures were maintained in the fumigation vault within ± 2° F. with a hot water heating system controlled by a thermostat.

After fumigations at 60° F. and 80° F. were completed, two fumigants and two kinds of seed were deleted from the tests conducted at 95° F. Carbon tetrachloride was deleted because it is not generally used as a commercial fumigant and no adverse effect was found following its use at 60° F. and 80° F. The commercial mixture, carbon tetrachloride + carbon disulfide + sulfur dioxide + inert ingredients, was removed from the 95° F. tests because of its injurious effect on germination in the 60° F. and 80° F. tests.

Cotton and barley seed were deleted because of the limitations of time and facilities.

Introduction of Insects

Principal emphasis in this study was placed on determining the effect of fumigants on germination. However, their effectiveness in insect control also was evaluated. The insects used were adults of the rice weevil, *Sitophilus oryza* (Linn)., and the confused flour beetle, *Tribolium confusum* Duval. One hundred adults of each species were placed in round steel cages measuring ¼ inch by 3 inches. These cages contained slits large enough to permit the fumigants to penetrate but small enough to keep the insects from escaping. The cages were inserted into a 50-pound sack of grain sorghum which was placed in the fumigation vault. A fresh sack of grain was used for each fumigation. For controls, 100 test insects of the same species were placed in cages in a grain mass outside the fumigation vault for the 24-hour fumigation. At the completion of each fumigation, mortality counts were made of both treated and control groups.

Fumigation

The fumigation room was a concrete atmospheric vault containing 1,543 cubic feet. The walls and ceiling were painted with vinyl mastic paint to minimize the diffusion of the gases from the vault.

The vault was equipped also with an exhaust fan and a recirculation system, which circulated 50 cubic feet of air per minute. The system was operated continuously during each 24-hour fumigation. Air was recirculated by pulling it through a duct at the top of the vault and exhausting it at the bottom.

Connections were built into the door for introducing fumigants and for plastic tubes which were used to draw gas concentration samples from the vault during fumigations.

Immediately before fumigation, seed samples were removed from the storage room and exposed to room temperature (75° F.) for 2 hours. The samples were then removed from the polyethylene bags and placed in small Osnaburg cotton bags, which were transferred immediately to a wire platform in the fumigation vault.

The insects were introduced in the manner previously discussed and the door was sealed. Liquid fumigants were sprayed into the vault from a specially constructed steel cylinder. Hydrocyanic acid was introduced from a standard pressurized (45 to 50 pounds per square inch) steel cylinder. Methyl bromide was introduced from 1 pound pressurized cans.

Thirty-eight separate fumigations were performed. Each lot of seed was fumigated for 24 hours. At the end of this time, the exhaust fan was operated until gas residues were removed from the vault.

Two Fumigations

To determine the effect of two fumigations on germination, seed were retreated at 95° F. after an initial treatment at 80° F. For the reasons discussed under "Fumigation Temperature," seed were not subjected a second time to two of the fumigants (carbon tetrachloride and a mixture of carbon disulfide, carbon tetrachloride, sulfur dioxide and inert ingredients).

After the first fumigation at 80° F., the seed were transferred from the cloth bags back to the plastic ones and replaced in the storage room. The second fumigation was conducted approximately 2 months later. Before fumigation at 95° F., seed moisture content was readjusted when necessary in the manner discussed under "Moisture Content of Seed."

Germination Analysis

After each fumigation test, seed were collected from treated and check samples for germination analysis. Germination tests were conducted according to the procedure presented in the Proceedings of the Official Seed Analysts except that two 100-seed samples were used in each test instead of four (2). A total of 2,232 samples was analyzed.

Postfumigation Storage

After seed for initial germination tests had been removed from the 1,000-gram samples fumigated at 60° F. and 80° F., the remainder of the sample was returned to the polyethylene bags. The bags were stored at room temperature for 12 months. After this period had elapsed, a second germination test was performed. Comparisons of the rates of germination decline were made between fumigated and unfumigated samples.

EFFECT OF FUMIGANTS ON INSECTS

Following every fumigation the insect mortality was 100 percent. Both the rice weevil and the confused flour beetle were eliminated. The mortality of check populations of these insects which were not fumigated was never greater than 5 percent.

EFFECT OF FUMIGANTS ON GERMINATION

Discussion by Crops

CORN

Hydrogen cyanide—Fumigation with cyanide had no immediate effect on germination of white corn except under combined high moisture (15 percent) and temperature (95° F.) conditions. Independently, these factors did not reduce germination.

Germination was significantly lower 12 months after fumigation with cyanide at high temperature (80° F.) when the moisture content of the seed was 13 or 15 percent. Fumigations at low moisture (11 percent) or low temperature (60° F.) did not increase the rate of germination decline. When white corn was fumigated twice (at 80° F, then at 95° F.), a reduction occurred following treatment at the higher moisture levels (13 and 15 percent).

Germination of yellow corn immediately after treatment was unaffected by one or two fumigations with hydrogen cyanide. A significant reduction occurred after 12 months' storage of yellow corn treated at high (15 percent) moisture and high temperature (80° F.).

Methyl bromide — A reduction in germination occurred at all three moisture levels when high temperature (95° F.) prevailed during fumigation. Germination of seed with a moisture content of 15 percent was not affected at 60° F., but declined at 80° F. and dropped sharply at 95° F. for both varieties.

Twelve months after fumigation, germination was lowered by methyl bromide fumigation in all treatments, except the one in which the lowest moisture (11 percent) was combined with the lowest temperature (60° F.). No white corn seed and only 1 percent of the yellow corn seed germinated after treatment at 15 percent moisture and 80° F. High temperature during fumigation had a more severe effect than did high moisture content of the grain.

A second fumigation caused a serious decline in grain germination with the lowest moisture content (11 percent). The decline became progressively more severe at the higher moisture levels (13, 15 percent).

Carbon tetrachloride—Fumigation with this material caused no immediate germination reduction at any of the combinations of moisture contents (11, 13, 15 percent) and temperatures (60° F., 80° F.) at which it was used. It was included in initial tests to determine whether it reduced germination in the commercial fumigant mixtures that incorporate it in their composition. This material was removed from the tests conducted at 95° F. and those involving two fumigations, since it is not a commercial fumigant and no effect was found after fumigation with it at 60° F. and 80° F. Germination records after 12 months' storage were obtained for both white and yellow corn fumigated at 60° F. and 80° F., and no reduction was observed which exceeded that of the untreated samples.

Carbon tetrachloride + ethlyene dibromide—The only reduction in germination occurred in the white corn sample which was treated at the highest moisture content (15 percent) and the highest temperature (95° F.).

After 12 months' storage of white corn treated at 60° F. and 80° F., reductions in germination greater than those in the checks occurred in every sample fumigated at both higher moisture levels (13, 15 percent). Similar results were obtained with yellow corn except that germination was not impaired by fumigation of seed at the middle moisture level (13 percent) at 60° F.

Two fumigations of white corn reduced germination of seed at the two higher moisture levels (13, 15 percent). Germination of yellow corn was not reduced by two fumigations.

Ethylene dibromide + ethylene dichloride + carbon tetrachloride—The only reduction in germination occurred in the white corn sample which was treated at the highest temperature (95° F.) and the highest moisture (15 percent).

When samples of both varieties were stored for 12 months, a reduction caused by fumigation occurred in every sample treated at the higher temperature (80° F.) This reduction grew progressively greater as moisture content increased. A germination decline also occurred after treatment at the lower temperature (60° F.) and the highest moisture level (15 percent).

Two fumigations reduced germination of both varieties only at the higher moisture levels (13, 15 percent).

Carbon disulfide + carbon tetrachloride + sulfur dioxide + inert ingredients—The only reduction at the lower moisture level (11 percent) occurred in yellow corn fumigated at 80° F. At the medium moisture level (13 percent), decline in germination of yellow corn occurred following fumigation at 60° F. and 80° F., but white corn was affected only at the higher temperature. At 15 percent moisture, a reduction in both varieties occurred at both 60° F. and 80° F.

After 12 months' storage of seed treated at 60° F. and 80° F., a germination reduction greater than that in the check sample occurred under every temperature and moisture condition.

Due to the pronounced effect of this material on germination, it was not included in the tests conducted at 95° F., and no second fumigation was performed.

Carbon tetrachloride + carbon disulfide + inert ingredients—No reduction in germination occurred except in the sample of white corn treated at the highest seed moisture content (15 percent) and the highest temperature (95° F.).

After 12 months' storage of both white and yellow corn fumigated at 60° F. and 80° F., germination reductions occurred in all grain treated at 80° F. The only decrease in germination at 60° F. occurred in seed with the highest moisture content (15 percent).

Two fumigations caused a germination decline of white corn at both the higher moisture levels (13, 15 percent) and of yellow corn at all three moisture levels (11, 13, and 15 percent).

SORGHUM

Hydrogen cyanide — No germination reduction occurred after one or two fumigations with hydrogen cyanide on either of the two varieties of sorghum included in the test.

No reduction in germination greater than that in the check sample occurred after 12 months' storage.

Methyl bromide—A single fumigation with methyl bromide impaired germination in samples of both varieties fumigated at high temperature (95° F.) and medium and high moisture levels (13, 15 percent). Germination of variety 7078 was reduced following fumigation at 80° F. and 15 percent moisture. No reduction occurred when grain was fumigated at 11 percent moisture regardless of temperature during treatment.

After storage for 12 months, germination of all samples of both varieties fumigated at 80° F. declined significantly regardless of moisture content. Germination of Plainsman seed was reduced by treatment at the lower temperature (60° F.) and high moisture (15 percent). Variety 7078 was adversely affected by fumigation at the lower temperature (60° F.) and medium moisture (13 percent). It is probable that treatment of grain at 60° F. and 15 percent moisture also had an effect on this variety.

Two fumigations caused an increasingly drastic reduction in germination of seed of both varieties from the lowest (11 percent) to the highest seed moisture level (15 percent).

Carbon tetrachloride—No decline in germination followed fumigation with carbon tetrachloride at any of the seed moisture contents (11, 13, 15 percent) or temperature levels (60° F., 80° F.). Because this material was included only to determine whether it reduced germination in commercial fumigant mixtures in which it was contained, it was not included in tests conducted at 95° F. or those involving two fumigations.

Germination tests performed after storage of treated sorghum for 12 months on two samples of each variety treated at 60° F. disclosed a greater reduction than that which occurred in the check. Seed moisture apparently was not involved since the reduction occurred in samples at each level. Carbon tetrachloride was the only fumigant used which caused a germination reduction at 60° F. and not at 80° F.

Carbon tetrachloride + ethylene dibromide—No germination reduction occurred after a single fumigation with this material.

After 12 months' storage of Plainsman seed, germination declined in seed treated at the highest moisture level (15 percent) at both temperatures (60° F., 80° F.). Erratic results were obtained with Variety 7078. A reduction in germination occurred in samples treated at low temperature (60° F.) and low and medium moisture (11, 13 percent) and at high temperature (80° F.) and high moisture (15 percent).

Two fumigations only impaired germination of seed containing 11 percent moisture. It is probable that the decline which occurred was caused by sample variability.

Ethylene dibromide + ethylene dichloride + carbon tetrachloride—Both varieties of sorghum responded almost identically to fumigation with this combination of materials. A germination decrease occurred only in the treatment combining the highest temperature (95° F.) and the highest seed moisture (15 percent).

Germination of both varieties was similarly affected after 12 months' storage. In Plainsman, a decline greater than that found in the check occurred in seed treated at the higher temperature (80° F.) regardless of moisture content. The germination of Variety 7078 was affected identically except that there was no reduction in seed containing 11 percent moisture.

Two fumigations reduced germination of both varieties only at the highest moisture level (15 percent).

Carbon disulfide + carbon tetrachloride + sulfur dioxide + inert ingredients—Germination reduction of Plainsman seed occurred in every sample fumigated with this material. Although seed of Variety 7078 were less severely affected, germination declined in all samples fumigated at the highest moisture (15 percent).

After 12 months' storage, germination of both varieties was reduced below that of the check in every sample except one.

Due to the adverse effect of this compound on germination, it was excluded from the tests conducted at 95° F. and no second fumigation was performed.

Carbon tetrachloride + carbon disulfide + inert ingredients—The only reduction in germination occurred in Plainsman seed fumigated at high moisture (15 percent) and high temperature (95° F.). Variety 7078 was similarly affected following fumigation at 95° F. and 13 percent moisture.

After storage for 12 months, erratically distributed reductions in germination occurred. Plainsman seed were affected at high moisture (15 percent) and low temperature (60° F.) and at low (11 percent) and medium (13 percent) moisture at high temperature (80° F.). Germination of Variety 7078 was reduced by fumigating at low temperature (60° F.) and medium moisture (13 percent) and at high temperature (80° F.) and medium (13 percent) and high (15 percent) moisture.

Two fumigations reduced germination of all samples of Plainsman. Seed of Variety 7078 were adversely affected only by fumigation at the highest moisture level (15 percent).

BARLEY

Due to the limitations of time and facilities, tests to determine the effects of fumigants on barley were conducted at three seed moisture levels (11, 13, 15 percent) in combination with only the two lower temperatures (60° F., 80° F.). No samples were fumigated twice.

Hydrogen cyanide — Fumigation at 60° F. did not affect germination of barley, but did cause reduction in samples treated at 80° F. at the higher moisture level (15 percent).

Germination tests 12 months later did not reveal any reductions. Either the hydrogen cyanide caused a transient reduction or the initial decline in the two samples was due to sample variations.

Methyl bromide — Reductions occurred following treatment at the higher temperature (80°) and the two higher moisture levels (13, 15 percent).

After 12 months' storage, significant declines in germination appeared in all treatments except the one combining the lowest temperature (60° F.) and the lowest moisture (11 percent).

Carbon tetrachloride
Ethylene dibromide + carbon tetrachloride
Ethylene dibromide + ethylene dichloride + carbon tetrachloride

The three fumigants above caused no decrease in germination immediately after fumigation or after 12 months storage regardless of temperature (60° F., 80° F.), or moisture content during fumigation.

Carbon disulfide + carbon tetrachloride + sulfur dioxide + inert ingredients—Germination was reduced at the lower temperature (60° F.) and the two higher moisture contents (13, 15 percent). One reduction occurred at the higher temperature (80° F.) and low moisture level (11 percent).

After 12 months' storage, the pattern was slightly changed. Fumigation adversely affected germination in all samples treated at the higher temperature (80° F.) and in lots fumigated at 60° F. and high (15 percent) moisture.

Carbon tetrachloride + carbon disulfide + inert ingredients—Fumigation apparently did not affect germination adversely.

OATS

Hydrogen cyanide — Fumigation did not cause a reduction in germination immediately or after a 12-month storage period regardless of temperature or moisture content during fumigation.

No immediate adverse effects on germination were observed following two fumigations.

Methyl bromide—The only reduction occurred in seed treated at 95° F. at both higher moisture levels (13, 15 percent).

After storage for 12 months, declines in germination occurred in all samples fumigated at the higher temperature level (80° F.) regardless of moisture content.

Two fumigations reduced germination at all moisture levels.

Carbon tetrachloride—This chemical did not reduce germination immediately or after 12 months' storage regardless of temperature (60° F., 80° F.) or moisture content (11, 13, 15 percent) during fumigation. Since it produced no harmful effects and is not a commercial fumigant it was removed from the test at 95° F. and those involving two fumigations.

Carbon tetrachloride + ethylene dibromide—No immediate adverse effects resulted from one or two fumigations. After 12 months' storage, germination of seed treated once was no lower than that of untreated seed.

Ethylene dibromide + ethylene dichloride + carbon tetrachloride—A single fumigation had no immediate effect on germination.

Twelve months after fumigation, a reduction in germination occurred in lots fumigated at the higher temperature (80° F.) and highest (15 percent) moisture content.

Two fumigations reduced germination at all moisture levels.

Carbon disulfide + carbon tetrachloride + sulfur dioxide + inert ingredients—The only reduction occurred in the treatment combining the highest moisture content (15 percent) and temperature (80° F.) level.

After 12 months' storage, a decline in germination occurred in seed treated at the highest grain moisture (15 percent) regardless of temperature (60° F., 80° F.). It is probable that fumigation at 80° F. had an effect on germination at all moisture levels, because there was a significant difference between treated and untreated seed at 11 percent and 15 percent and a near significant difference at 13 percent.

Because this material had a severe adverse effect on germination of seed, it was eliminated from the fumigants tested at 95° F. and no grain was fumigated with it a second time.

Carbon tetrachloride + carbon disulfide + inert ingredients—One or two fumigations with this material did not cause a decline in seed viability. After 12 months' storage, germination of seed treated once was no lower than that of untreated seed.

WHEAT

Hydrogen cyanide—One fumigation did not inhibit germination immediately or after 12 months' storage. Two fumigations caused no immediate decline in germination.

Methyl bromide—Germination was adversely affected after fumigation at high temperature (95° F.) regardless of moisture content of the grain. A reduction occurred at 80° F. when the moisture content was 15 percent.

After storage for 12 months, germination of treated wheat was less than that of the check in every sample regardless of temperature (60° F., 80° F.) or grain moisture content. The reduction was more severe at the higher temperature.

Two fumigations impaired germination at all moisture levels.

Carbon tetrachloride—No harmful effects on germination resulted from one or two fumigations.

Tests conducted after 12 months' storage of wheat fumigated once disclosed no decline in germination. This chemical was included to determine its effect on germination in fumigant mixtures in which it is incorporated. Since it had no harmful effect it was not included in tests conducted at 95° F. or those involving two fumigations.

Carbon tetrachloride + ethylene dibromide—Germination was not decreased by one or two fumigations regardless of temperature or moisture content during fumigation.

After storage of fumigated grain for 12 months, a decline in germination greater than that in the check occurred in every treatment regardless of temperature (60° F., 80° F.) or moisture content except in the treatment combining the lower temperature (60° F.) and the lowest moisture level (11 percent).

Ethylene dibromide + ethylene dichloride + carbon tetrachloride — One fumigation did not cause a decline in germination at any temperature or moisture level.

After 12 months' storage, reductions in germination greater than those in the check samples appeared in lots fumigated at the higher temperature (80° F.) and the two highest moisture levels (13, 15 percent). No reduction occurred in any sample treated at 60° F. regardless of moisture content or at 11 percent moisture regardless of temperature (60° F., 80° F.).

Two fumigations reduced germination at the two higher moisture levels (13, 15 percent).

RICE

Hydrogen cyanide—One or two fumigations of rice with hydrogen cyanide did not decrease germination regardless of treatment.

Germination tests conducted after 12 months' storage of rice which had been fumigated once did not reveal a reduction due to fumigation.

Methyl bromide—Germination of rice was reduced by fumigation at 15 percent moisture content but was not affected at 11 percent regardless of temperature during fumigation. In seed containing 13 percent moisture, reduction occurred when the temperature was 80° F. or 95° F.

After storage for 12 months, every sample treated at the higher temperature (80° F.) was adversely affected by fumigation regardless of moisture content during fumigation. The only reduction which occurred in grain treated at 60° F. appeared in the sample whch contained 15 percent moisture.

Two fumigations caused a severe decline in germination of rice with a moisture content of 11 percent, and totally inhibited germination of seed containing 13 percent and 15 percent moisture.

Carbon tetrachloride — Fumigation did not affect germination of rice treated at 60° F. and 80° F. immediately or after 12 months' storage regardless of moisture content of the grain. Because this material was included initially only to determine whether it reduced germination in commercial mxtures in which it is contained, it was removed from the tests at 95° F. and those involving two fumigations.

Carbon tetrachloride + ethylene dibromide—A reduction in germination followed fumigation at high temperature (95° F.) and high grain moisture contents (13, 15 percent).

A germination reduction significantly greater than in the check occurred after storage of fumigated grain for 12 months in the treatment combining high moisture content (15 percent) and high temperature (80° F.) during fumigation.

Two fumigations did not significantly reduce germination. However, a decline was apparent.

Ethylene dibromide + ethylene dichloride + carbon tetrachloride—Germination tests immediately after fumigation disclosed a reduction in the treatment at the highest seed moisture content (15 percent) and the higher temperatures (80° F., 95° F.).

After 12 months' storage following fumigation, germination was significantly less than the check in samples fumigated at the higher temperature (80° F.) and the higher moisture levels (13, 15 percent).

Two fumigations caused germination of rice to be reduced regardless of moisture content of the seed.

Carbon disulfide + carbon tetrachloride + sulfur dioxide + inert ingredients — Fumigation caused a decline in germination of all samples treated at the highest moisture level (15 percent.) The decline was more severe after 12 months' storage. No other treatments affected germination.

The use of this material was discontinued after fumigation at 60° F. and 80° F. It was eliminated from the tests conducted at 95° F., and those involving two fumigations because of its adverse effect on germination of several grains.

Carbon tetrachloride + carbon disulfide + inert ingredients — No decline in germination caused by one fumigation occurred immediately or after storage of treated grain for 12 months regardless of temperature or seed moisture content during fumigation.

Two fumigations caused a reduction in germination of rice with a moisture content of 13 percent or 15 percent.

COTTON

Due to limitations imposed by time and facilities, tests to determine the effects of fumigants on germination of cotton were conducted only at the lower temperatures (60° F., 80° F.). No seed were fumigated twice.

Hydrogen cyanide—Fumigation did not reduce germination immediately or after 12 months' storage regardless of temperature (60° F., 80° F.) or moisture content of the seed during fumigation. The apparent reduction in germination incurred in the sample treated at 60° F. and 8 percent moisture was probably due to sample variation.

Methyl bromide—Germination of cottonseed was reduced by fumigation at the higher temperature (80° F.) in grain with the highest moisture content (11 percent). Germination was not affected by any other combination of moisture and temperature treatments immediately or after 12 months' storage of treated seed.

Carbon tetrachloride
Ethylene dibromide + carbon tetrachloride
Ethylene dibromide + ethylene dichloride + carbon tetrachloride

The three fumigants above did not cause any reduction in germination immediately after fumigation or after 12 months' storage of fumigated seed. A significant difference in germination occurred between seed fumigated at 80° F. and 8 percent moisture content and the check, but this difference was probably caused by experimental variability.

Carbon disulfide + carbon tetrachloride + sulfur dioxide + inert ingredients — Fumigation with this compound caused no immediate decline in germination of cottonseed but after 12 months' storage slight reductions appeared in samples fumigated at the higher temperature (80° F.) and low and high moisture contents (8, 11 percent).

Carbon tetrachloride + carbon disulfide + inert ingredients—Germination was not affected following the use of this fumigant but reductions due to fumigation occurred after 12 months' storage. Although these reductions were slight and irregularly distributed through the treatments, they are probably of real significance. Declines occurred in lots treated at 60° F. and middle and high moisture (8, 11 percent) and at 80° F. and low moisture (6 percent).

Summary by Fumigants

Hydrocyanic acid—There was little inhibition of germination of seed of any crop used in this study following fumigation with hydrogen cyanide. Storage of fumigated grain for 12 months did not have an appreciable adverse effect. There was no instance in which germination was reduced following two fumigations, Table 3.

Apparently, hydrogen cyanide was the most satisfactory commercial fumigant used in the test from the standpoint of protection of seed crops from harmful insects without reducing germination. Variations in moisture content and temperature during fumigation did not affect germination of treated seed.

Methyl bromide — Fumigation with methyl bromide under certain conditions caused reductions in germination of all crops included in this study. The effects were increasingly severe as moisture content of the seed and temperature during fumigation were increased independently. Treatments combining high temperature (95° F.) and high moisture content invariably reduced germination significantly regardless of the crop. After storage of fumigated grain for 12 months, germination was reduced in treatments which were not immediately affected by fumigation. This effect was particularly noticeable in lots fumigated at the lower temperature and moisture content levels.

Two fumigations reduced germination of every lot of seed subjected to the treatment.

Carbon tetrachloride — Because rather large dosages of carbon tetrachloride are required to control several of the stored grain pests this chemical is not usually considered a commercial fumigant. It is included in commercial mixtures principally for its fire-inhibiting properties. It was included in this study to determine whether it was the constituent which reduced germination in fumigant mixtures in which it is incorporated.

There was no immediate reduction in germination of any seed included in the test from a single fumigation of carbon tetrachloride. No lots of seed were fumigated twice.

After 12 months' storage, significant germination declines appeared in two samples of both varieties of sorghum fumigated at low temperature (60° F.). No reduction appeared after treatment at 80° F.

Because carbon tetrachloride exhibited practically no adverse effect on germination when used independently, it is apparently not the ingredient which reduces germination in fumigant mixtures in which it is included.

Carbon tetrachloride (95 percent) + **ethylene dibromide** (5 percent)—The immediate reductions in germination caused by one or two fumigations with this compound were practically negligible. After storage of fumigated grain for 12 months, there were a considerable number of samples in which germination was reduced below that of unfumigated samples stored for the same period of time. There was a tendency for germination to be reduced more when fumigation took place at the higher temperature (80° F.) though several samples treated at 60° F. were affected also.

The addition of ethylene dibromide to carbon tetrachloride causes a germination decline of certain seed in storage, since fumigation with carbon tetrachloride alone did not reduce germination severely.

Ethylene dibromide (7.2 percent) + **ethylene dichloride** (29.2 percent) + **carbon tetrachloride** (63.6 percent). **(Dowfume** EB-5)—As noted previously, carbon tetrachloride had little adverse effect on germination while ethylene dibromide caused a considerable reduction in germination after storage for 12 months. The addition of 2.2 percent ethylene dibromide and 29.2 percent ethylene dichloride produced further effects. Single fumigations with this combination of chemicals slightly depressed germination immediately after fumigation.

There was no more adverse effect after storage than there was with the carbon tetrachloride-ethylene dibromide mixture discussed previously.

There was a definite increase in the number of samples in which declines in germination occurred following two fumigations. It is probable that this reduction can be attributed largely to the addition of ethylene dichloride since the percentage of ethylene dibromide in the mixture was increased only 2.2 percent. Apparently, both ethylene dibromide and ethylene dichloride cause reductions in germination when these chemicals are included with carbon tetrachloride in fumigant mixtures.

Carbon tetrachloride + carbon disulfide + sulfur dioxide + inert ingredients[1] (Stauffer 80-20) — Fumigation with the mixture containing this combination of ingredients caused a severe reduction in germination. Because of its adverse effect, it was eliminated from the tests before fumigations were performed at 95° F. and before any seed samples were fumigated a second time.

Unless inert ingredients are responsible, both carbon disulfide and sulfur dioxide reduce germination. In the discussion of the succeeding fumigant—a mixture of carbon tetrachloride, carbon disulfide and inert ingredients — it may be observed that germination was depressed following fumigation, indicating that carbon disulfide reduces viability.

The reduction was greater when sulfur dioxide was added, demonstrating that it further decreases germination.

Carbon tetrachloride (82.5 percent) + **carbon disulfide** (16.5 percent) + **inert ingredients** (1.0 percent). **(Dow Vertifume)**—There are few indications of an immediate adverse effect on germination following one fumigation with this compound.

[1]Percentages of each ingredient withheld by manufacturer.

TABLE 3. NUMBER OF SIGNIFICANT REDUCTIONS IN GERMINATION OF ALL CROPS FOLLOWING FUMIGATION AT VARYING TEMPERATURE AND MOISTURE LEVELS

Fumigant	Number reductions[1]											
	Immediate						After 12 months' storage					After two fumigations
	Moisture percent			Temperature (F.)			Moisture percent			Temperature (F.)		
	Low	Medium	High	60	80	95	Low	Medium	High	60	80	
Hydrogen cyanide	0	0	1	0	0	1	1	2	2	3	2	0
Methyl bromide	3	9	14	1	8	17	9	13	16	13	25	21
Carbon tetrachloride	—	—	—[2]	0	0	—	2	1	1	4	0	—[2]
Carbon tetrachloride + ethylene dibromide	0	1	2	0	0	3	3	7	11	9	12	3
Dowfume EB-5	0	0	6	0	2	4	3	6	9	2	16	15
Stauffer 80-20	—	—	—[2]	11	14	—	12	11	17	18	22	—[2]
Dow Vertifume	0	2	2	0	1	3	4	7	10	8	13	13

[1]Based on 27 samples in each category.
[2]Incomplete totals (omitted from 95° and two fumigation tests).

After 12 months' storage of fumigated seed, several reductions appeared which were significantly greater than those which occurred in untreated samples.

Two fumigations lowered germination of certain seed considerably below that of samples which were treated only one time.

Since carbon tetrachloride is relatively noninjurious, it is probable that this reduction may be attributed to the carbon disulfide in the mixture.

EFFECT OF FUMIGANTS ON SEED VIGOR

Seed viability is determined by counting the number of germinated normal seedlings after standard germination tests such as those which were used in this study. Seed vigor is also an important factor in the development of satisfactory plant stands. In this study, seed vigor was evaluated by observations of the speed of germination and the size of the seedlings. Consequently the vigor of seed is not revealed by germination percentages.

In some instances, the germination percentages of fumigated seed were not significantly different from those of check samples; however at the conclusion of germination tests, the seedling structures were slightly smaller than those observed in check samples. Another substantial loss of seed vigor was evidenced by slow seedling growth although the seedlings attained countable size by the end of the germination test.

Seed injured by some fumigants produced seedlings with certain structures which failed to grow. The primary root and plumule often became necrotic in corn and sorghum seed, largely due to overgrowth of molds on these weakened structures. The failure of certain seedling parts to develop often resulted in excessive growth of other parts of the same seedling. This abnormality was observed in such crops as corn and wheat. For example, corn seedlings fumigated with one material had essentially no root system, but plumule or shoot growth was vigorous. Some fumigated wheat seed had no plumule growth, but developed a normal root system. A different injurious effect was observed on seedling structures of oats and rice following the use of a fumigant. Oat seedlings had abnormally twisted plumules while rice seed exposed to the same conditions developed normal plumules, but the root systems were severely injured. Most abnormal seedling structures which appeared were evidence of seed weakness caused by such factors as high seed moisture content, temperature and fumigants. Fumigated seed of all crops produced seedlings that were less vigorous than nonfumigated seed even when germination percentages revealed little or no differences.

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Detailed Tables Available

Detailed tables from which much of the information in this publication was developed are available on request to the Department of Entomology, College Station, Texas.